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SYNERGY OF MULTIMODAL PEDAGOGY AND ARTIFICIAL INTELLIGENCE: METHODOLOGICAL FOUNDATIONS FOR THE PERSONALIZATION OF EDUCATIONAL TRAJECTORIES IN HIGHER EDUCATION

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Abstract
Contemporary higher education requires a transition from standardized programs to personalized educational trajectories. This article is devoted to the development of the methodological foundations for the synergy of Multimodal Pedagogy (MMP) and Artificial Intelligence (AI) as a key factor in achieving this goal. The implementation of AI makes it possible to analyze large volumes of data on a student's learning style and progress. Integration with MMP, which utilizes various perceptual channels (visual, auditory, kinesthetic), ensures the collection of multidimensional data. This is critically important, as traditional systems often fail to take into account a student's cognitive preferences, leading to reduced effectiveness. The use of AI for analyzing multimodal data allows for the dynamic adaptation of both the content and the format of the educational material, thereby avoiding cognitive overload. The paper presents a conceptual model of this synergy, which serves as a basis for creating adaptive educational platforms and next-generation intelligent textbooks. Special attention is paid to the practical

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aspects of applying the model to increase engagement and the quality of material assimilation. It is concluded that this integration represents a strategic direction for enhancing the effectiveness, engagement, and quality of higher education in the digital age.

Keywords: Multimodal pedagogy; artificial intelligence; personalized learning; adaptive learning; educational trajectories; EdTech; higher education.

Introduction

Digital transformation in Higher Education (HE) is characterized not just by replacing traditional tools, but by a fundamental restructuring of didactic approaches. In a context where the labor market demands graduates possess not only subject knowledge but also "21st-century competencies" (critical thinking, creativity, adaptability), traditional learning models oriented towards the "average" student are becoming ineffective.

The relevance of this study is determined by the urgent need to create mechanisms capable of considering the individual needs, pace, and learning style of each student. The solution to this problem lies in the integration of two groundbreaking concepts: Artificial Intelligence (AI), capable of deep analytics and adaptation, and Multimodal Pedagogy (MMP), aimed at utilizing various channels of information perception.

While AI offers algorithmic solutions for content adaptation and the formation of individual trajectories, MMP acts as the methodological basis for enriching the learning experience. The synergy of these two approaches—where AI analyzes how a student interacts with multimodal content (text, video, simulations) and dynamically changes the next modality of information delivery based on this analysis—represents a new, comprehensive scientific direction.

The purpose of the article is to develop and substantiate a conceptual model for the synergy of multimodal pedagogy and artificial intelligence, defining the methodological principles for creating adaptive educational trajectories in higher education.

In the context of digital globalization, a key challenge for higher education is overcoming the standardized approach. Differences in student learning styles,

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preparation levels, and cognitive abilities require tools that can dynamically adapt both the content and the form of information delivery. This is where the potential of Multimodal Pedagogy (MMP) lies; by utilizing the synergy of textual, visual, and interactive modalities, it creates a rich environment for knowledge acquisition. However, without an instrumental base capable of analyzing the massive amount of data generated in such an environment, the potential of MMP remains largely unrealized.

This instrumental function is assumed by Artificial Intelligence (AI). The integration of AI into educational platforms allows for a shift from static analysis to proactive learning management. Systems based on machine learning and neural networks can not only detect errors but also predict them, analyze the causes of difficulties, and, most importantly, determine the most effective perceptual channel for a specific student. Thus, AI is transformed from an auxiliary tool into a key mechanism for personalization, ensuring the optimal load on the student's cognitive resources.

Therefore, the objective of this study is not merely to describe AI or MMP separately, but to develop a conceptual model of the synergy between these two directions. We proceed from the hypothesis that only the integration of the flexible methodology of MMP with the powerful analytics of AI can ensure the creation of truly adaptive educational trajectories. This model will serve as the methodological foundation for designing intelligent learning systems and will allow for the assessment of the pedagogical effect of dynamically changing content modalities based on the individual needs of the student.

2. Methodology

This article presents an analytical review and theoretical-methodological substantiation based on the results of a systemic study of digital transformation issues in higher education. The following research methods were used to achieve the stated goal:

- **Theoretical analysis and systematization** of scientific literature on cognitive learning theories (Paivio's dual coding theory, Mayer's cognitive theory of multimedia learning) and the principles of AI development in education.
- **Systemic approach** for considering the educational environment as a complex structure where AI, MMP, and the student are interconnected.

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- **Method of generalization and synthesis** for forming the conceptual model of MMP and AI integration.

The logic of the research was built on the principle of general to particular: macro-analysis of global digitalization trends, detailed study of the potential of AI and MMP individually, followed by the synthesis of these two elements to form a new model of personalization.

Key Aspects of MMP and AI Synergy

2.1. Multimodal Pedagogy as the Basis for Data Collection

Multimodal Pedagogy (MMP) is an approach that recognizes that learning occurs through interaction with various semiotic resources: textual, visual, auditory, spatial, and kinesthetic. MMP strives to engage different types of intelligence and perceptual styles, offering various ways to interact with content.

The key principle of MMP is the principle of synergy: different modalities should not duplicate but complement and enhance each other's perception. For example, animation can explain a dynamic process that is difficult to describe with text. In the context of personalization, MMP is not just a tool for creating rich content, but also a platform for obtaining multidimensional data about the student. Traditional systems only record test answers and time spent on a page. Multimodal content, combined with sensors and AI analysis systems, allows for the assessment of:

- **Engagement and attention:** through analysis of interaction with video (pauses, repetitions), 3D models, or VR simulations.
- **Preferred perceptual channel:** which content formats (auditory, visual, interactive) are most effective for a particular student.

2.2. The Role of AI in Dynamic Adaptation of the Educational Trajectory

Artificial Intelligence in education aims to create **adaptive and personalized educational trajectories**. AI systems analyze large volumes of data (academic performance, reaction time, frequency of errors) and based on this, form a detailed profile of the learning process.

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Key AI functions for personalization:

✓ Preference analysis and risk prediction: AI identifies strengths and weaknesses, predicts areas where difficulties may arise, and identifies at-risk groups.

✓ Dynamic complexity adaptation: AI regulates the complexity of tasks and the depth of material presentation in real-time.

✓ Providing targeted feedback: AI tutors offer timely and individualized recommendations, freeing the instructor from routine tasks.

2.3. Conceptual Model of MMP and AI Synergy

The synergistic model, based on the integration of MMP and AI, operates through the following cycle:

- **Multimodal Content Delivery (MMP):** The student is offered material in a format optimal for the topic (e.g., a complex process is explained through interactive 3D animation; theoretical substantiation—through text).
- **Collection and Analysis of Multidimensional Data (AI):** The AI system collects data on how the student interacts with this content (viewing duration, repetitions, answers, actions in the simulator). AI analyzes **which** modality led to better assimilation or difficulty.
- **Adaptive Decision Making (AI):** Based on the analysis, AI makes a decision about the next step in the trajectory.
  - *Example 1 (Difficulty with text):* If the analysis shows that the student spent a long time on the text section and failed to answer a question, AI may offer an **alternative modality**—a brief video overview or infographic with key points.
  - *Example 2 (Successful assimilation):* If the student quickly and successfully completed an interactive module, AI offers a **transition to more complex material** or a practical task requiring the creation of their own multimodal response.

This model allows for the adaptation of not only the **complexity** of the material but also its **format**, which is the key element of genuine personalization in accordance with the student's cognitive characteristics.

3. Discussion. Challenges and Perspectives

Despite the obvious advantages, the implementation of this model is associated with a number of challenges that require further research:

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- **The "Black Box Problem" (XAI):** It is necessary to develop Explainable AI (XAI) so that instructors and students understand the data and principles on which the decision to change the educational trajectory is based.
- **Data Confidentiality:** The collection of extensive multimodal data about students requires strict security and protection protocols.
- **Pedagogical Retraining:** Instructors require training in new methods of working in an environment where AI becomes a key learning facilitator.

The implementation of the synergistic model of multimodal pedagogy and AI, despite its revolutionary potential, is associated with a number of fundamental methodological and ethical challenges that require careful discussion. The first and most significant challenge is the "Black Box Problem" of AI algorithms. When AI makes a decision to change the content modality or trajectory complexity, instructors and students often do not understand the input data and logical rules that led to it. This lack of transparency can undermine trust in the system and complicate the pedagogical control process. The solution to this problem lies in developing Explainable AI (XAI) systems, which will not only propose an adaptive solution but also provide a clear justification for their actions to all participants in the educational process.

A second critically important aspect concerns data ethics and confidentiality. The synergistic model presupposes the collection of the most detailed information about the student, including their behavioral reactions, emotional state (through analysis of multimodal data), and cognitive preferences. This vast array of Educational Big Data (Edu Big Data) requires strict adherence to international data protection protocols. Clear mechanisms for anonymization and depersonalization must be developed to prevent the unauthorized use of this sensitive information. Furthermore, the issue of Algorithmic Bias remains debatable: if the training samples of AI systems contain hidden prejudices, this can lead to incorrect recommendations and, consequently, to the exacerbation of existing educational inequality.

Finally, the practical implementation of the model dictates the need for comprehensive pedagogical and technological retraining. The transition to adaptive multimodal platforms requires the instructor to transform their role from a transmitter of knowledge to an architect and validator of the educational experience. Educators must be able not only to work with and interpret AI reports

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but also be prepared for the continuous updating and creation of high-quality multimodal content (3D models, VR scenarios). From a technological perspective, universities must overcome the digital divide by ensuring equal access for all students to high-speed internet and specialized equipment necessary for full interaction with immersive and adaptive learning resources.

The Perspectives for the development of this area lie in the creation of hybrid educational systems, where AI and the educator work in close tandem, utilizing the strengths of each: AI—for large-scale analytics and micro-adaptation, and the educator—for providing emotional intelligence, critical reflection, and the formation of value orientations. Future research should focus on developing standardized metrics for the pedagogical effectiveness of adaptive multimodal systems, allowing for precise measurement of the impact of modality changes on the depth of knowledge assimilation and the formation of professional competencies outlined in your monograph.

4. Conclusion

The integration of multimodal pedagogy and artificial intelligence represents a key direction for the development of personalized learning in higher education. MMP enriches the educational content and ensures the multidimensional collection of data on the learning process, while AI uses this data to create dynamically adaptive and individualized educational trajectories.

The proposed conceptual model of MMP and AI synergy ensures a transition to truly adaptive learning, where not only the pace and complexity but also the format of information presentation is adjusted. Successful implementation of this model, considering ethical and methodological challenges, will enable universities to prepare graduates with key 21st-century competencies and ensure an improvement in the quality and accessibility of higher education.

Thus, the developed conceptual model of MMP and AI synergy confirms its methodological significance in the context of higher education. It provides a clear framework for transitioning from the fragmented use of digital tools to comprehensive, systemically adaptive learning. The implementation of this model does not merely automate the learning process; it fundamentally changes its quality, guaranteeing that every student receives knowledge in the most effective modality and at the optimal pace for them. This, in turn, contributes to increasing not only

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academic performance but also internal motivation, as well as reducing the risk of cognitive overload often associated with standardized learning materials.

The successful implementation of the principles outlined in this work has strategic importance for the national higher education system. The deployment of AI-driven multimodal platforms based on this model allows for the training of graduates who possess high adaptability and necessary digital competencies. Perspectives for further research will be related to the practical validation of the proposed model based on intelligent learning systems, such as the "Intelligent Textbook" detailed in your monograph, and to the development of standardized protocols for the safe and ethical use of multimodal educational data.

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